

## Denton Infinity 22 E-beam Standard Operating Procedures for Electron beam Evaporation



**Coral name:** E-beam Evap 2  
**Model:** Infinity 22  
**Location:** CNST NanoFab, Building 215, Room B104

## Denton Electron Beam Evaporator #2

### TOOL CONTACT INFORMATION

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### APPLICATIONS

- **Vacuum deposition of metallic and dielectric thin films**

### SYSTEM

- 6-pocket electron gun turret
- Oxygen ion gun for ion-assisted deposition
- Base vacuum: 1E-7 Torr
- Pumpdown from atmosphere to 3E-6 Torr in ~ 20 minutes

### SAFETY

- No unusual hazards during normal operation
- Do not attempt to unjam turret if stuck. Contact NanoFab staff for help.

### MATERIAL RESTRICTIONS

- No high vapor pressure materials (Bi, Pb, Sn, Zn, Cd, etc.). No In, Li.
- **Maximum thickness per layer 200nm.** Any exception must be approved by NanoFab staff

### REQUIREMENTS

- Only qualified users may operate
- **MUST LOGIN TO CORAL AND ENABLE TOOL BEFORE OPERATING**
- **Fill out logbook**
- Make sure materials are loaded in correct pockets
- Make sure beam is centered in pocket (LED indicators and direct view)

### PROHIBITIONS

- Never touch any internal part on the tool with bare hands or contaminated gloves
- Contact staff before depositing any new material

### OTHER INFORMATION

- Always check the material file parameters in film deposition controller prior to evaporation
- **Report problem to the maintenance staff and leave a note on Coral**
- **Always leave tool pumped down when you are finished**

## Overview

- This tool is an electron beam evaporator (also referred to as “electron gun” or “e-beam”). Six materials are pre-loaded in the gun’s 6 pockets. An ion gun can be used to pre-clean the substrates or/and densify dielectric films. The substrates are loaded on a planetary fixture and undergo a double rotation ensuring a uniformity better than 2% over a 150mm diameter wafer. The capacity is (4) 150mm or 100mm wafers, or (8) 75mm or 50mm wafers. Fixtures are available for small pieces.
- These instructions are divided into three parts:
  - I. Automatic operation using an existing process and material
  - II. Manual operation using the hand-held remote control or deposition controller knob
  - III. Creation of a process and film using the SQC310C Inficon deposition controller
- The system is equipped with an electron gun containing 6 pockets, each 25cc in capacity. The pockets are referred to as Source 1-Pocket 1, Source 1-Pocket 2,..., Source 1-Pocket 6.
- Refer to the following five figures showing the five graphical user interface (GUI) screens needed to do a run:

Fig. 1 **Overview** (starting screen; accessed by closing the Auto Control screen)

Fig. 2 **Auto Control** (accessed from Overview)

Fig. 3 **Deposition Configuration** (accessed from Auto Control)

Fig. 4 **E-beam Control**

Fig. 5 **Ion Pre Clean Configuration**

- The color code for all the GUI screens is the following:  
**Green: ON or Satisfied**  
**Red: OFF or Not Satisfied**

## Special Notes and Restrictions

- You must be trained to use this tool
- This tool is reserved for the following metals: Ag, Au, Pt, Co, Cr, Cu, Fe, Ti, W, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>. Evaporation of materials other than these requires prior authorization from NanoFab staff.
- The following materials may **NOT** be deposited:
  - Sn, Zn, Cd, Bi, Li, In
- When you are done with your work, **always leave the chamber under vacuum**. Minimize the time the chamber is left at atmosphere.
- **Note of caution:** the electrical power required to obtain a stable evaporation depends not only on the material but also on the exact type of crucible (“liner”) you are using. Do not run

an automatic process stored in the Inficon SQC310C deposition controller unless you are sure it is the right one for your evaporation. The first time you are using either a new material and/or crucible liner, always do a test run using the remote control and write down the adequate times and power levels. You can then create a new film and process in the 310 for your purpose.

- All seven interlock indicators on the Overview screen (Fig. 1) should be green after you have enabled the tool in Coral. If not, notify NanoFab staff member. Do not proceed any further with the machine.
- The cryopump temperature indicator should read 9-14K. If not, notify NanoFab staff member. Do not proceed any further with the machine.

## I. Automatic Operation

### 1. Vent chamber

In the Overview screen (Fig. 1), press Auto Control (light blue, bottom right). This brings up the Autocontrol screen (Fig. 2). Press Auto, top left in System Control box. The tab turns from red to green. Press Auto Vent; the tab turns green, showing “running”. Press Close. This brings back the Overview screen. It will take ~ 4 min. for the chamber to come to atmosphere. Open door.

### 2. Load material and wafer and pump-down

Press Manual. Press E-beam Control. Open shutter. Take note of the positions of your source materials: pockets 1 to 6. You can view each pocket by enabling the crucible motor and incrementing the crucible number (Fig. 4). Close shutter. Place wafer in planetary. Close and latch door.

Press Close. On the Overview screen, press Auto Control (light blue, bottom right). On the Auto Control screen, press Auto (top left), press Auto Pump.

### 3. Deposition

- Press Deposition Configuration (Fig. 3). Enter the following:
  - Process start pressure: 3.0E-6 Torr. It will take ~ 15 minutes to reach this base pressure from atmosphere.
  - Rotation setpoint in percent of maximum speed (typ. 25%)
  - Heat: toggle “selected/not selected”. If selected, enter Heat Setpoint in °C
  - For ion assisted deposition, toggle “Ion Assist” to “selected”. Typical conditions are:
    - Neutralizer Setpoint= 20A
    - Drive Setpoint= 2A
    - Gas #1 Setpoint=20sccm.
  - Press Close
  - For ion wafer precleaning, press “Ion Preclean Config” on Auto Control screen.

**NOTE:** *This feature is not implemented yet. It requires Argon gas. DO NOT use ion precleaning at this time.*

Typical conditions are:

- Neutralizer Setpoint= 20A
- Drive Setpoint= 2A
- Gas #1 setpoint=20sccm
- Preclean soak time 30 sec.
- Press Close
- On the Auto Control screen, leave “*Vent after deposition*” red. Do not activate: you must allow the source 5 minutes to cool down before venting after the end of the deposition.
- High Voltage Power Supply cabinet: turn on High Voltage and Control circuit breakers (up position) if needed
- On the Telemark TT-10/15 Control, turn key to ON to enable the high voltage power supply.
- Switch Telemark Sweep Power Supply Controller to ON (Fig. 6)
- Toggle to “Sweep Select” to select the right-hand side sweep unit
- Set Telemark Sweep Select to AUTO. In this mode, the sweeps are automatically selected as follows:
  - Pocket 1 = sweep 1
  - Pocket 2 = sweep 2
  - Pocket 3 = sweep 3
  - Pocket 4 = sweep 4
  - Pocket 5 = sweep 1
  - Pocket 6 = sweep 2
- You have the choice to also manually select sweeps 1-2-3 4 by switching to “Manual” and using the 4-position rotary switch
- Adjust sweep to pattern indicated in Table 1.
- Select process on Inficon SQC310 controller as follows:
  - Go to Main Screen (Fig. 7)
  - Click Process menu
  - Scroll to desired process (fig. 8)
  - Press Select
  - Press Edit (Fig. 9)
  - Press Edit again
  - Edit process (Figs 10 and 11) following parameters in Tables 2 and 3
  - Go back “To Main”
  - Click “Film Menu” (Fig. 7)
  - Scroll to desired film (Fig. 12)
  - Click Edit
  - Refer to Fig. 13. Verify parameters using Tables 2 and 3. Change adjustable parameters ONLY if needed (Table 2). Do NOT change the fixed parameters (Table 3)
  - Click on Films Conditions
  - Refer to Fig. 14. Verify parameters using Tables 2 and 3. Change adjustable parameters ONLY if needed (Table 2). Do NOT change the fixed parameters (Table 3)
  - Click back To Main

- You should now be back to Fig. 7
- Press Next Menu
- Toggle to **Auto/Manual** (i.e. **NOT** Manual/Auto)
- From the Auto Control screen, press Autodeposition
- Attention: **Do NOT** go into “**System Menu**” or “**Configure Sensors**”. These parameters may only be changed by a NanoFab staff.
- During deposition, you can use the Quick Edit Screen to change some parameters “on the fly”. Refer to Fig. 15 and 16. You can also toggle between different displays using “Next Menu” and “Next Graph” (Fig. 15)
- Once the process is completed, wait 5 minutes for the pocket to cool down
- Press Autovent to bring the chamber to atmosphere
- Remove your wafer, latch door and press Autopump.
- **Fill out Runlog sheet in logbook**

## II. **Operation Using the Remote Power Handset or Control Knob**

The remote control is typically used when depositing a new material to empirically determine the power values needed to melt the material and obtain given evaporation rates. These values can then become parts of a new material and film for subsequent automatic operation.

- Vent chamber, load wafer and material, pump down as described under “Automatic Operation”
- Wait for the process start pressure to almost be reached (approx. 15 minutes)
- In Overview, select Manual (Fig. 1)
  - Select E-Beam Control
  - Rotation ON (Fig. 3)
  - Close
- For ion beam pre-clean
  - Click Ion Source Control (Fig. 1)
  - Gas#1 ON at 20sccm (Fig. 5)
  - Neutralizer current ON at 20A
  - Drive current ON at 2A
  - Proceed with ion beam cleaning
  - Leave ion beam ON if you use ion assisted deposition (IAD)
  - If not, shut off Gas#1, Neutralizer and Drive
- If you use heat
  - Press Heat Control (Fig. 1)
  - Enter set point in °C
  - Power ON
- On the Inficon SQC310C controller, select a process:
  - Process menu (Fig. 7)
  - Select process (Fig. 8)

- Review all the process and film parameters as described in the Automatic Operation section
- On Quick Edit/Next menu screen (Fig. 15), toggle to **Manual/Auto** (i.e. **NOT** Auto/Manual)
- Wait for the process start pressure (also temperature if heat is used) to be reached (approx. 20minutes from autopump start). In Overview, set System Control to Manual. Then press E-beam control (upper right, blue button). Refer to Fig. 4.
  - Sweep select: 1, 2, 3 or 4
  - Crucible control: rotate to desired pocket 1, 2, 3, 4, 5 or 6 by pressing Crucible # and Motor Enable
  - Control mode: Remote
  - Rotation: 25 % and ON
  - Shutter: OFF
  - System enable
    - System Power ON (green)
    - Reset
    - HV Power ON (green)
    - Emission ON (green)
- Start increasing the power using the hand-held remote control or turning the knob on the SQC310C. A reasonable ramp rate is typically one click (0.1%) per second to progressively heat the source.
- When you get to 5% power, stop increasing and check the sweep pattern to make sure the electron beam is **centered and sweeping the source without encroaching on the copper hearth or the liner**. There are two ways to choose a sweep pattern:
  - Set the Telemark Sweep Select to AUTO and select the sweep on the touch screen 1, 2, 3 or 4, or
  - Set the Telemark Sweep Select to Manual and select the sweep using the rotary switch
  - Look at the source and adjust the position, frequency and amplitude of the sweep. Note: For each sweep, you can choose either a triangle or spiral pattern. Refer to Table1 to choose the proper sweep pattern for your film. The Modulation Amplitude knob adjusts the collapse of the spiral pattern
- When you reach 10% power, **check the sweep pattern again** and readjust if needed
- Open shutter. It is preferable to open the shutter when some metal is already evaporating (i.e. at predeposit power). If you don't know, 15% is a good default value.
- Keep increasing power until the desired deposition rate is achieved. As an example, for Al, 17% power yields 0.1Å/s and 21.5% yields 1.0Å/s. Note that the exact power level will vary with the sweep pattern.

- When the desired thickness is attained, close the shutter and decrease power to zero
- On E-beam Control GUI screen, press:
  - Rotation OFF
  - Emission OFF
  - HV Power OFF
  - Leave System Power ON
- If heat was used, press heat Control
  - Power OFF
  - Close
- If ion beam was used
  - Neutralizer OFF
  - Drive OFF
  - Gas#1 OFF
- Make sure chamber temperature is below 60°C before venting
- Vent chamber: Go to the Auto Control screen, press Auto, then press Autovent.
- Remove your wafer, latch door and press Autopump.
- **Fill out runlog sheet in logbook.**

### III. Operation of the Inficon SQC310 Deposition Controller

#### 1. Quick Tips

- **Quick Edit**: allows to change some menu parameters as run progresses
- **Stop Layer**: shuts off power supply, rotation.
  - Leave *Auto/Manual* in *Auto*
  - Press *Autodeposition* on GUI to start again. Note that *Start Layer* is used only in Manual Mode
- **GUI Abort**: same as Stop Layer. Press *Autodeposition* to restart
- Can switch to **Manual/Auto** during autodeposition
  - Control power supply with knob or remote control
  - Can switch back to *Auto/Manual*
- **Auto/Manual**: Toggles between Auto and manual control. When *Auto/Manual* is shown, output power is set by the SQC-310 to achieve the programmed deposition rate. When *Manual/Auto* is shown, the control knob sets the output power.
- **Zero**: Re-zero thickness reading
- **Start Layer**: Each layer in a process can be defined as Auto Start or Manual Start. Auto Start layers begin immediately on completion of the previous



layer. Manual Start layers wait for the operator to press Start layer. Only visible when waiting to start a manual Start layer

- **Start/Reset**: starts or halts the current process. Sets all outputs to zero.
- **Next Layer**: Sequences through each process layer. Use this key to start or restart the process at any layer. Only visible when the process is stopped.
- **Next menu**
  - **Next Graph**: displays Rate, Power, Thickness, Rate/Thickness/power table
  - **Next Display**: displays Rate-Dev-Thick-Power or Rate-Rate SP-Thick-Thick SP
- **Sensor Info table**: displays active sensors, freq, life, rate, thickness
  - Sensor 1 normally in use. Sensor 3 is its back up
  - Sensor 2 can also be used. Sensor 4 is its back up

## 2. Tooling Factors

Tooling factors are correction factors that take into account the different flux “seen” by the crystal sensors and the wafers due to their different distance and angular positions with respect to the source.

The controller uses three tooling factors

- System Tooling Factor: *always leave at 100%*
- Sensor Tooling Factor
  - Sensors 1 and 3: *leave at 115%*
  - Sensors 2 and 4: *leave at 97%*
- Film Tooling Factor: refer to Table 2 (Film Menu) to find values for individual materials.

## 3. Crystal Averaging

You can turn on sensors 1 and 2 simultaneously and read the average

## 4. Definitions

Several terms will be used repeatedly throughout this manual. It is important that you understand each of these terms.

- **Material**: A physical material to be deposited. A database of 100 materials is stored in the SQC-310. Three parameters completely define a material: Name, Density, and ZFactor. A table of common materials, their density, and Z-Factor is listed in Appendix A.

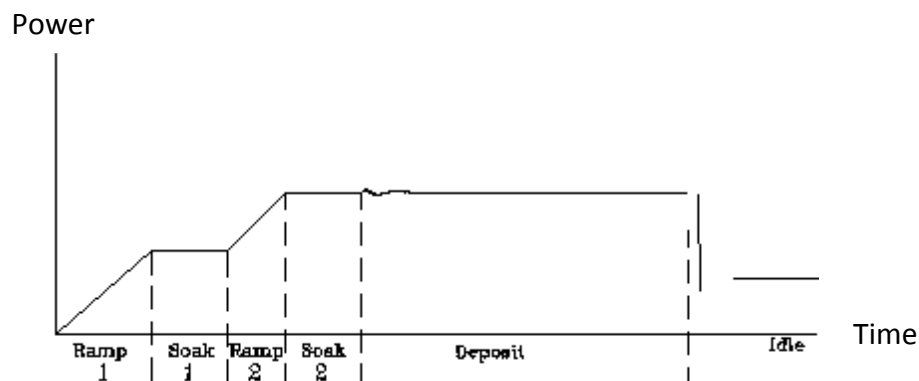
- **Film**: A film describes in detail how a material will be deposited. It includes the material definition and all of the preconditioning, deposition, and post conditioning variables

necessary to accurately deposit the material. Because the film definition does not include rate and thickness information, a single film can be used in several different layers and processes. The SQC-310 stores up to 50 films.

- **Layer:** Layers are the basic building blocks of processes. A layer consists of a film and the thickness and rate setpoints for that stage of the process. Layers also define which outputs and sensors will be used at that point in the process. Co-deposition of multiple films occurs when more than one output is active during a layer.

- **Process:** A process is a sequence of layers to be deposited. The SQC-310 can store up to 100 processes, consisting of a total of 1000 layers.

- **Phase:** A step in the deposition cycle. Preconditioning phases include Ramp 1, Soak 1, Ramp 2, and Soak 2. Deposit phases include indexer rotate, shutter delay, deposition, and deposition rate ramps. Post-conditioning phases include Feed Ramp, Feed, and Idle Power.



## 5. Defining a Film- See Fig. 13

A film is a material to be deposited, plus all of its associated setup parameters. Keep in mind that a film can be used in multiple layers, or even multiple processes. Editing a film's parameters will cause changes to every location where the film is used.

- To define a film, press **Next Menu** until Film Menu is shown. Press **Film Menu**. A list of 25 films (or <Empty>) will be displayed. To define a new film, scroll to <Empty> and press **Edit Name**. Scroll through the character set and **Insert** each character for the film name. Press **Save** to return to the Film Select Menu. The new Film name is added to the list of existing films. Press **Edit** to display the parameters for this film.

- P Term is the proportional gain, which is the % process rate change divided by the % input power change.
- The I Term (integral) sums the rate deviations over time to more accurately achieve the rate setpoint.

- The D Term (derivative) speeds response to sudden changes in rate. Volumes have been written on determining the proper PID settings. See the section on Loop Tuning later in this chapter for a common PID loop tuning procedure. Start with P=25, I=.5, D=0.
- Film Tooling adjusts for differences in actual versus measured thickness for this film (material). This parameter is used to adjust for material specific dispersion patterns. See Xtal Tooling in the System Parameters menu for the more commonly used tooling correction.
- Pocket selects the source pocket used for this film. This parameter requires that the System Menu, Source Setup be configured for an indexer (Chapter 3).
- The next chapter will cover Crystal Quality and Stability. For initial operation leave Quality and Stability disabled.
- With Material highlighted, press **Edit** to scroll through the list of available materials. Select the desired material and press **Enter**. You could also change the Density and ZFactor for the selected material, but it is unlikely those values are wrong. You cannot add materials, but you can edit the Name, Density, and Zfactor of one of the 100 existing materials.

**5.1 Film conditioning:** *See Fig. 14.* Adjusts the output power level to achieve a desired material state before and after deposition. Press **Film Conds** to enter the film conditioning menu.

- Ramp1 starts at 0% power and increases the power during Ramp1 Time to the Ramp 1 power level. Set the Ramp 1 Power and Time to gradually bring the material to a near molten state. Set the Soak 1 Time to a value that will allow the material to homogeneously achieve that state.
- Ramp 2 is used to slowly bring the material to a power level that nearly matches the desired deposition power. Use Soak 2 to hold the material at that level until deposition (i.e. rate control) begins.
- If you use wire feed to replenish material after deposition, set the Feed Power and times as required. The idle conditioning phase typically ramps output power back toward zero at the end of a process.
- From the Film Conds menu, press **Prev Menu** to return to the main Film Params menu.

**5.2 Deposit Controls.** *See Table 3 “deposit Controls”.* The Deposit Controls menu contains parameters that modify operation during the deposition phase.

- Shutter delay causes the SQC-310 to delay opening the shutter until the process has stabilized at the desired deposition rate. Capture is the % rate deviation that must be achieved to open the shutter and go to the Deposit phase. Shutter delay is the maximum amount of time to wait for capture to be achieved. Set Shutter Delay and

Capture to zero to disable this feature.

- During co-deposition, the SQC-310 waits for all films to achieve capture before moving to the deposit phase. If any film fails to achieve rate capture within its programmed shutter delay time, an error occurs.
- If the SQC-310 is unable to maintain the desired deposition rate (for example, out of material or a bad sensor), one of three actions is possible. Keep trying (Ignore), set power to zero to halt deposition (Stop), or maintain constant power (Hold) and extrapolate thickness from the last good rate reading. Until your process is known and stable, it is best to leave the Control Error setting on Ignore.
- Rate sampling can extend sensor life in high rate processes. Select Cont (continuous) to disable rate sampling. A Time selection closes the shutter for a fixed time, then opens the shutter for a fixed time to sample the rate. Acc Based (accuracy based) sampling closes the shutter for a fixed time, then opens the shutter until the desired rate is achieved. Rate Sampling assumes a very stable process!

**5.3 Configure Sensors.** This menu defines operation of the film when a sensor fails. *Only NanoFab staff is allowed to change these settings.*

- Crystal Fail mode selects the action taken when a sensor crystal fails. Select Halt to halt the process on failure. Select Halt Last if multiple sensors are used for this film.
- Select Timed Power to enter Timed Power mode using the last good rate/power measurements. Select Switch to Backup to switch to a backup crystal.
- The next three parameters define which position of a multi-crystal sensor is used as the primary, and which is the backup. The number of sensor positions displayed is determined by the sensor configuration on the Sensors & Sources screen of the System Menu.

## **6. Defining a Process – See Fig. 9**

To define a process, press **Next Menu** until the Process Menu SoftKey is shown. Press **Process Menu**. A list of 100 processes (or <Empty>) will be displayed.

- To define a new process, scroll to <Empty> and press **Create**. A new Process# is added to the list of existing processes. Press Edit Name to change the default name.
- Press **Select**, then **Edit** to display the sequence of layers and films that comprise the selected process. To add the first layer, press **Insert New**.
- Select a film from the films screen and press **Insert Normal**.

- To add more layers, scroll to below the last layer and press **Insert New**. Layers are always added above the selected layer.
- To insert a layer in a sequence of layers, scroll to below the desired location in the layer sequence, and press **Insert Layer**. Select a film from the list and press **Insert Normal** to insert the new layer above the selected layer. The selected layer and subsequent layers will be shifted down.
- *Hint: When building a process it may be easiest to add a “dummy” last layer and keep inserting above that layer. When the process is complete, delete the “dummy” layer.*
- The display below shows two films being Codeposited with Film1, then a fourth film being deposited as an additional layer. While layers are always numbered sequentially, the films are sequential only for this example. Any film can be used in any layer.
- To delete a layer, highlight it in the Layer Select menu and press **Delete**.
- To move or duplicate a layer, highlight it in the Layer Select menu and press **Copy**. On the Paste menu, press **Paste** to replace a layer. Press **Insert Normal** or **Insert CoDep** to insert it above the highlighted layer. A copy of the layer is saved to the cut/paste clipboard memory.
- **Note:** *Once a film is assigned to a process layer, you cannot change the film. Instead, cut the layer, then insert a new layer and select the desired film.*

## 7. Defining a Layer – See Figs. 10 and 11

To edit a Process Layer, press **Process Menu**. Select the desired process, then press **Edit**. Finally, select the desired layer and press **Edit....**

- Initial Rate and Final Thickness are the main process setpoints for the film used in this layer. Time Setpoint and Thickness Limit are secondary values that can activate a relay when they are reached.
- Start Mode controls operation in multi layer processes. In Auto Start the layer starts immediately on completion of the previous layer. Manual Start waits for a user signal via the front panel, digital input, or communications port to start the layer. Don't confuse this Manual Start mode with the Manual Power SoftKey function.
- The SQC-310 can use multiple sensors to measure a film's deposition rate and thickness. If multiple sensors are selected, an average of the sensors is used. Set each sensor that will be used to measure this film to ON.
- The Source entry assigns the layer to a specific SQC-310 rear panel source output. The layer (and associated film parameters) will be applied to the selected output.
- Assign the Max, Power, Min. Power, Power Alarm Delay and Slew Rate appropriate for

the material and your power supply. For now, set Max Power & Slew rate to 100%. Set them to lower values if you find that small power changes cause excessively large changes in deposition rate. Leave Rate Deviation alarms at 0% for now.

- Rate Ramps allow the PID controlled deposition rate to change over time, under PID control. Each rate ramp has a starting thickness, an elapsed time to ramp to the new rate, and a new rate setpoint. Each process layer can have up to two rate ramps.

Table 1 – Recommended Sweep Patterns

Material	Sweep Pattern	Crucible	Amplitude
Co	Spiral	Copper	3 bars each side of zero
W	Spiral	Fabmate	3 bars each side of zero
Other Metals	Spiral	Any	4 bars each side of zero
Si	Spiral	Fabmate	6 bars each side of zero
TiO <sub>2</sub>	Spiral	Fabmate	4 bars each side of zero
Other Dielectrics	Triangle	Fabmate	6 bars each side of zero

Table 2 – Process and Film Adjustable Parameters – Metals

		Ag	Co	Cr	Cu	Fe	Pt	Ti	W
Crucible		Fabmate	Copper	Fabmate	Fabmate	Copper	Copper	Fabmate	Fabmate
Power at 1Å/s	%	15	17.5	3.2	18	5.8	29	11	48.5
Ion Beam	Y/N	N	N	N	N	N	N	N	N
Final Temp (1kÅ)	°C	32	35	35	45	35	59	42	225
<b>Process Menu</b>	<b>Unit</b>								
Init rate	Å/s	0.1 to 5	0.1 to 1	0.1 to 2	0.1 to 5	0.1 to 2	0.1 to 1	0.1 to 2	0.1 to 2
Final thickness	kÅ								
Sensor 1	On/Off	On	On	On	On	On	On	On	On
Sensor 2	On/Off	Off	Off	Off	Off	Off	Off	Off	Off
Sensor 3	On/Off	Off	Off	Off	Off	Off	Off	Off	Off
Sensor 4	On/Off	Off	Off	Off	Off	Off	Off	Off	Off
Max. power	%	35	35	15	35	15	50	20	65
<b>Film Menu</b>									
P Term		10	10	10	10	10	75	10	10
I Term	sec	0.7	0.7	0.7	0.7	0.7	1	1	0.7
D Term	sec	0	0	0	0	0	0	0	0
Film Tooling	%	82	100	103	80	113	84	100	140
Pocket (typical)	1 to 6	5	5	4	5	5	3	2	5
Material		Ag	Co	Cr	Cu	Fe	Pt	Ti	W
Density (g/cm <sup>3</sup> )	g/cm <sup>3</sup>	10.5	8.71	7.2	8.93	7.86	21.4	4.5	19.3
Z Factor		0.529	0.343	0.305	0.437	0.349	0.245	0.629	0.163
<b>Film Conditions</b>									
Ramp 1 Power	%	11	13	2.5	14	4.5	25	8	43
Ramp 1 Time	hh:mm:ss	1.5min	1.5min	1.5min	1.5min	1.5min	3min	1min	5min
Soak 1 Time	hh:mm:ss	1min	1min	1min	1min	1min	30sec	1min	1min
Ramp 2 Power	%	13	15	3	16	5.2	28	9.5	45
Ramp 2 Time	hh:mm:ss	1min	1min	1min	1min	1min	30sec	1min	1min
Soak 2 Time	hh:mm:ss	1min	1min	1min	1min	1min	30sec	1min	1min



Table 2 cont'd – Process and Film Adjustable Parameters – Dielectrics and others

		SiO <sub>2</sub>	SiO <sub>2</sub>	SiO <sub>2</sub>	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	Si
Crucible		Fabmate	Fabmate	Fabmate	Fabmate	Fabmate	Fabmate	Fabmate
Power at 1Å/s	%	9	9	9	9	15	15.5	13
Ion Beam	Y/N	N	Y	N	Y	N	N	N
Final Temp (1kÅ)	°C	51	155	51	155	73	109	56
<b>Process Menu</b>	<b>Unit</b>							
Init rate	Å/s	0.1 to 5	0.1 to 5	0.1 to 5	0.1 to 5	0.1 to 5	0.1 to 2	0.1 to 4
Final thickness	kÅ							
Sensor 1	On/Off	On	On	Off	Off	On	On	On
Sensor 2	On/Off	Off	Off	Off	Off	Off	Off	Off
Sensor 3	On/Off	Off	Off	On	On	Off	Off	Off
Sensor 4	On/Off	Off	Off	Off	Off	Off	Off	Off
Max. power	%	15	15	15	15	20	25	25
<b>Film Menu</b>								
P Term		10	10	10	10	10	10	10
I Term	sec	1	1	1	1	0.7	0.7	0.7
D Term	sec	0	0	0	0	0	0	0
Film Tooling	%	100	88	100	90	156	139	117
Pocket (typical)	1 to 6	1	1	1	1	3	5	6
Material		SiO <sub>2</sub>	SiO <sub>2</sub>	SiO <sub>2</sub>	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	Si
Density (g/cm <sup>3</sup> )	g/cm <sup>3</sup>	2.2	2.2	2.2	2.2	3.97	4.26	2.32
Z Factor		1.07	1.07	1.07	1.07	0.336	0.4	0.712
<b>Film Conditions</b>								
Ramp 1 Power	%	7	7	7	7	11	13	11
Ramp 1 Time	hh:mm:ss	1min	1min	1min	1min	1min	2.5min	1.5min
Soak 1 Time	hh:mm:ss	30sec	30sec	30sec	30sec	1min	1min	1min
Ramp 2 Power	%	8	8	8	8	13	15	12
Ramp 2 Time	hh:mm:ss	1min	1min	1min	1min	1min	1min	1min
Soak 2 Time	hh:mm:ss	30sec	30sec	30sec	30sec	1min	1min	1min

**Table 3 – Process and Film Fixed Parameters**

Process Menu		Unit
Time setpoint	hh:mm:ss	0:00:00
Thickness setpoint	kÅ	0
Start Mode	Auto/Man.	Auto
Source	Src1/Src2	Src1
Min. Power	%	0
Power Alarm Delay	sec	99
Slew rate	%/sec	99.9
Rate Dev. Attention	%	0
Rate Dev. Alert	%	0
Rate Dev. Alarm	%	0
Ramp 1	En/Dis	Disabled
Ramp 2	En/Dis	Disabled

Film Menu		
Xtal Qual., Rate Dev.	%	100
Xtal Qual., Counts	Disabled	Disabled
Xtal Qual., Single	Hz	Disabled
Xtal Qual., Total	Hz	Disabled

Film Conditions		
Feed Power	%	0
Ramp Time	hh:mm:ss	0:00:00
Feed Time	hh:mm:ss	0:00:00
Idle Power	%	0
Ramp Time	hh:mm:ss	0:00:00

Deposit Controls		
Shutter Delay	hh:mm:ss	0:00:00
Capture	%	0
Control Error		Ignore
Rate Sampling		Continuous

Table 3 – Process and Film Fixed Parameters (cont'd)

Parameter	Value
Sensr1 Crystal Fail Mode	Switch to backup
Crystal Position	1
Backup Sensor	2
Backup Crystal Position	1
Sensr2 Crystal Fail Mode	Backup
Crystal Position	1
Backup Sensor	1
Backup Crystal Position	1
Sensr3 Crystal Fail Mode	Switch to backup
Crystal Position	1
Backup Sensor	4
Backup Crystal Position	1
Sensr4 Crystal Fail Mode	Backup
Crystal Position	1
Backup Sensor	1
Backup Crystal Position	1

Table 4 – System Menu

Parameter	Value	Unit
Period	0.75	second
Simulate Mode	off	on/off
System Tooling	100	%
Min. Freq.	$5 \times 10^6$	Hz
Max. freq.	$6 \times 10^6$	Hz
Dev. Graph Limit	50	%
Rate Filter Alpha	0.25	
RS232 Communic.	115200	Baud
Password Enable	off	On/off
Password	1111	
Alarm Sounds	Enabled	En/Dis
Alert Sounds	Disabled	En/Dis
Attention Sounds	Disabled	En/Dis

Table 5 – Inputs

	Name	Color	Number	Use
1	Input1_LS1	green	Input 1	LS
2	Input2_LS2	green	Input 2	LS
3	Input3_LS3	green	Input 3	LS
4	Input4_LS4	green	Input 4	LS
5	Src1_InPosition	green	Input 5	Src
6	Input 6	green	Input 6	
7	Input 7	green	Input 7	
8	Input 8	green	Input 8	
9	Input 9	green	Input 9	
10	Input 10	green	Input 10	
11	Input 11	Red	Input 11	
12	Input 12	Red	Input 12	
13	Input 13	Red	Input 13	
14	Input 14	Red	Input 14	
15	Input 15	Red	Input 15	

Table 6 – Relays

	Name	Color	Number	Use
1	Snsr1&2_Dualshtr	Red	Relay 9	Snsr
2	Snsr3&4_Dualshtr	Red	Relay 13	Snsr
3	Source1_BCD_Bit0	Red	Relay 10	Src
4	Source1_BCD_Bit1	Red	Relay 11	Src
5	Source1_BCD_Bit2	Red	Relay 12	Src
6	Process-Hold	Red	Relay 1	LS
7	Relay_LS6	Red	--	LS
8	Final_Thickness	Green	Relay 5	LS
9	Final_Thickness	Green	Relay 6	LS
10	Source1_shutter	Red	Relay 4	Src
11	Relay	Red	--	
12	Relay	Red	--	
13	Relay	Red	--	
14	Relay 14	Red	Relay 14	
15	Relay 15	Red	Relay 15	
16	Relay 16	Red	Relay 16	

Table 7 – Sensors and Sources

	Name	Value
1	Sensor 1	Dual Crystal, Primary
2	Sensor 2	Dual Crystal, Secondary
3	Sensor 3	Dual Crystal, Primary
4	Sensor 4	Dual Crystal, Secondary
1	Source 1	Indexer
2	Source 2	Single Source
3	Source 3	Single Source
4	Source 4	Single Source

Table 8 – Logic Menu

	Logic Statements	Color
1	Statement 1	Green
2	Statement 2	Green
3	Statement 3	Green
4	Statement 4	Green
5	Statement 5	Red
6	Statement 6	Green
7	Statement 7	Green
8	Statement 8	Green
9-31	<Empty>	yellow
32	Statement 32	Red

Table 10 – Tooling Factors

	<b>Tooling Factor (%)</b>
System	100
Sensor 1	115
Sensor 2	115
Sensor 3	97
Sensor 4	97
Film	See Table 2

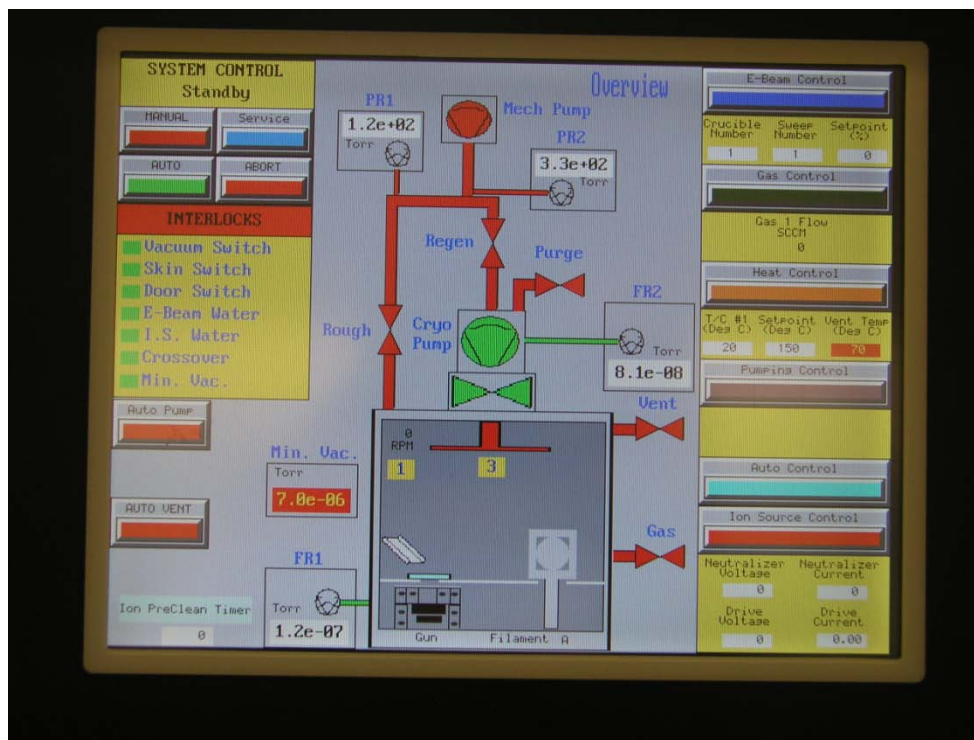


Figure 1 - Overview Screen

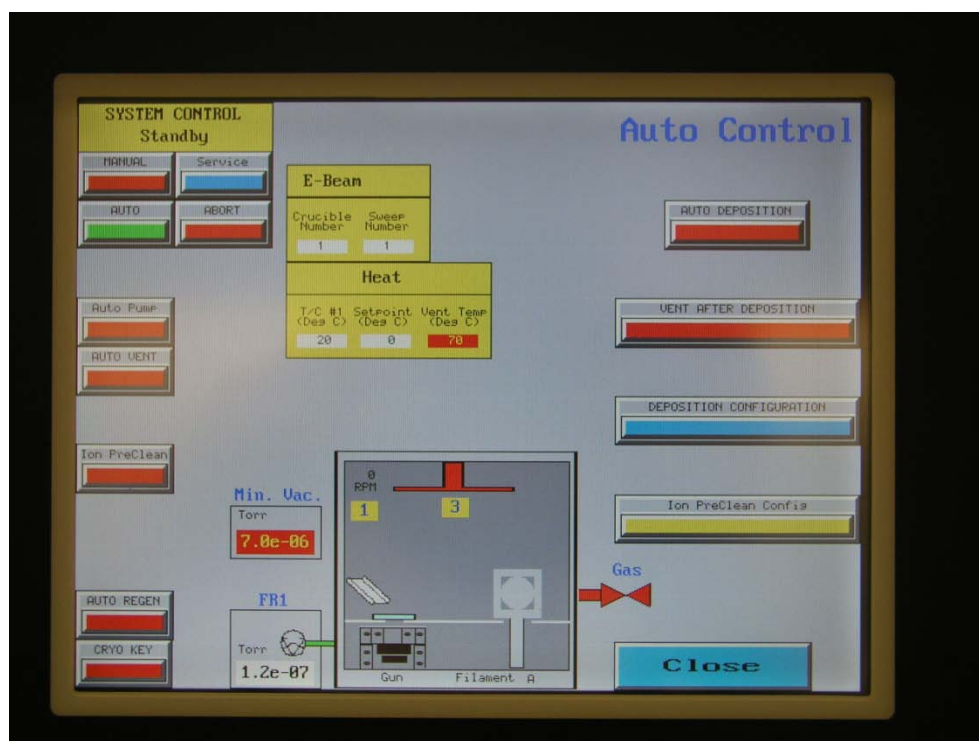


Figure 2 - Auto Control Screen

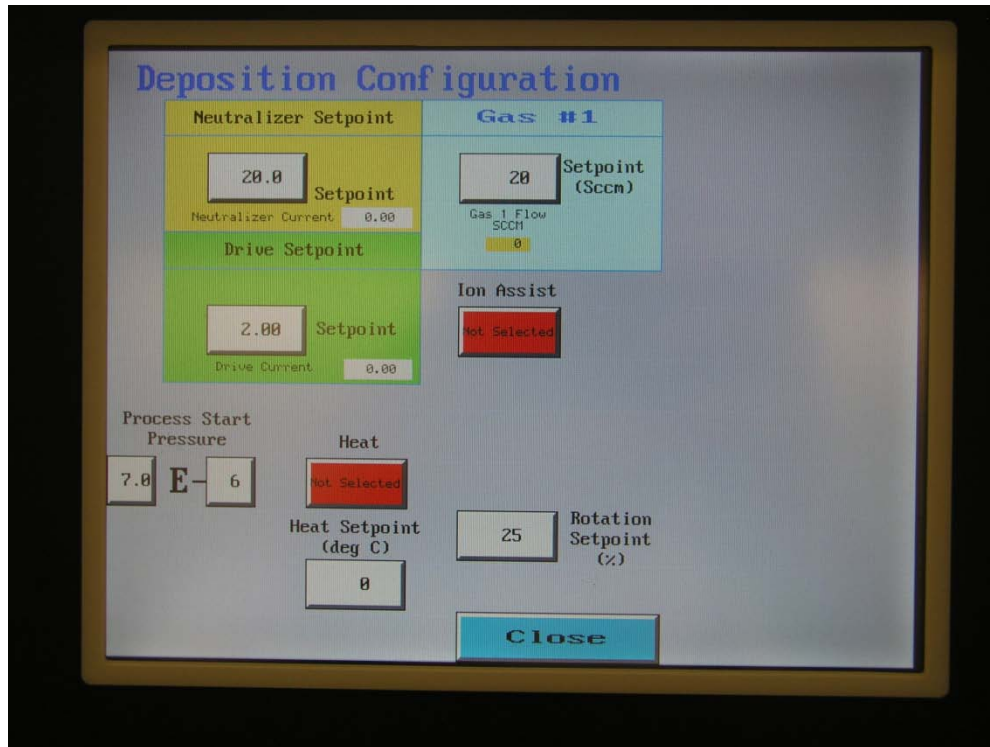


Figure 3 - Deposition Configuration

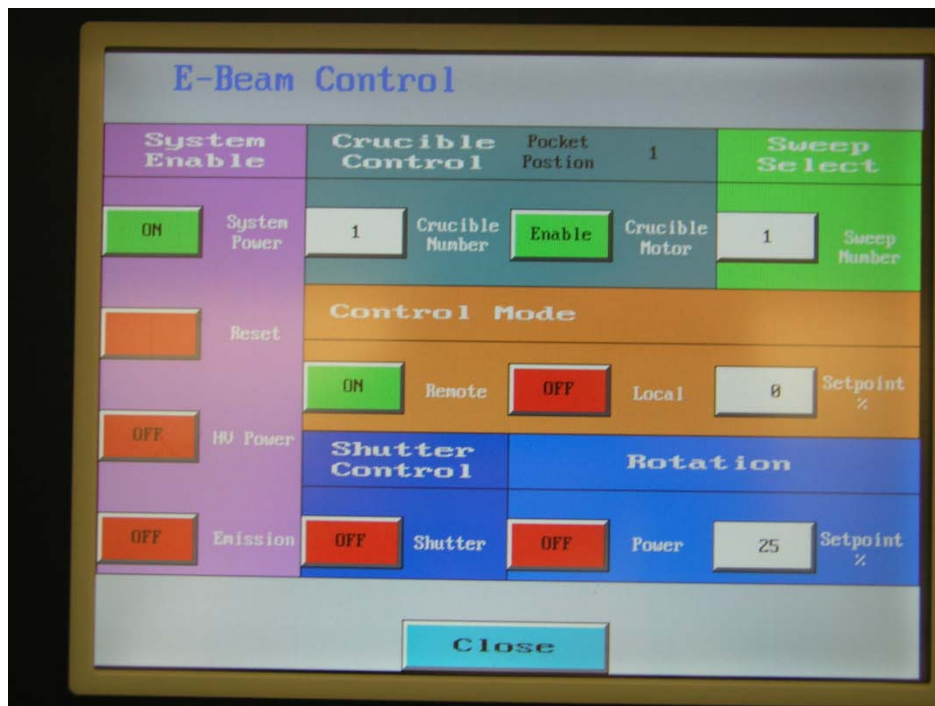


Figure 4 - Electron Beam Control



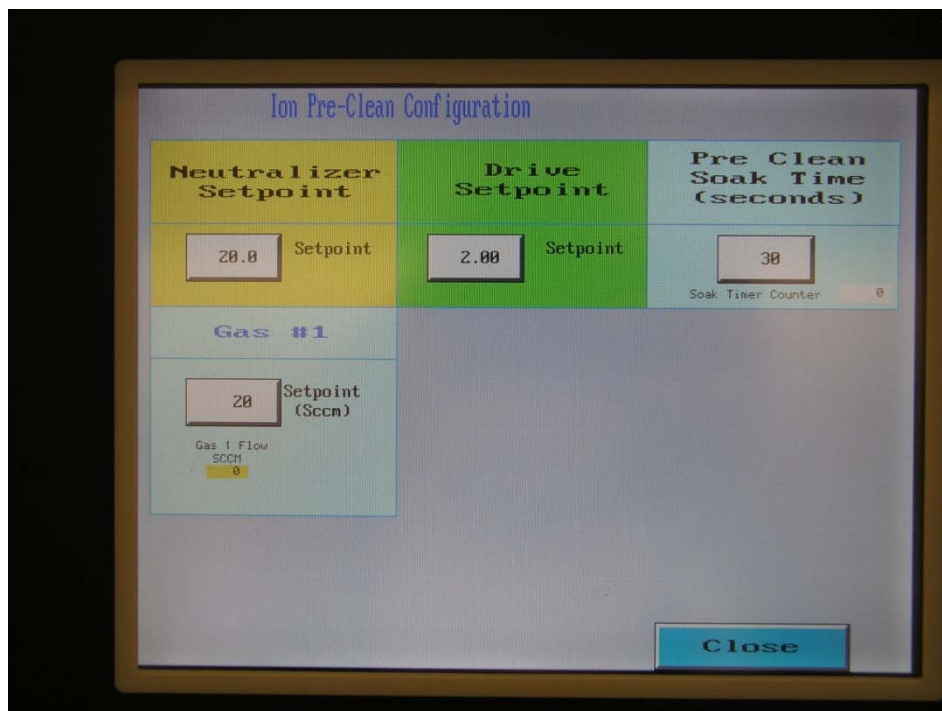


Figure 5 - Ion Pre Clean Configuration



Figure 6 - Sweep Control Unit

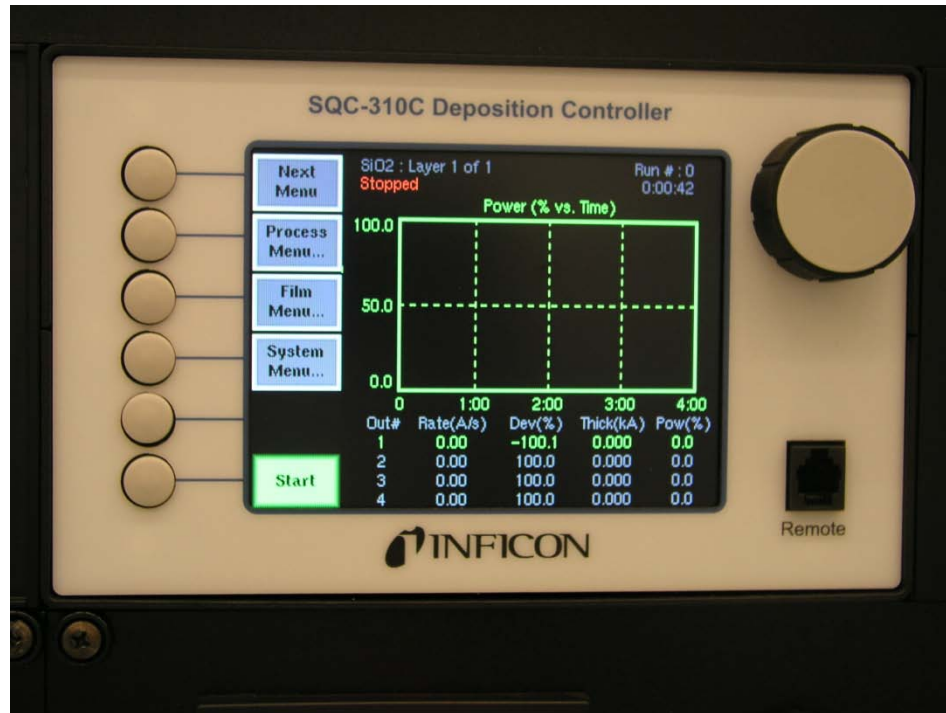


Figure 7 - SQC310C Deposition Controller

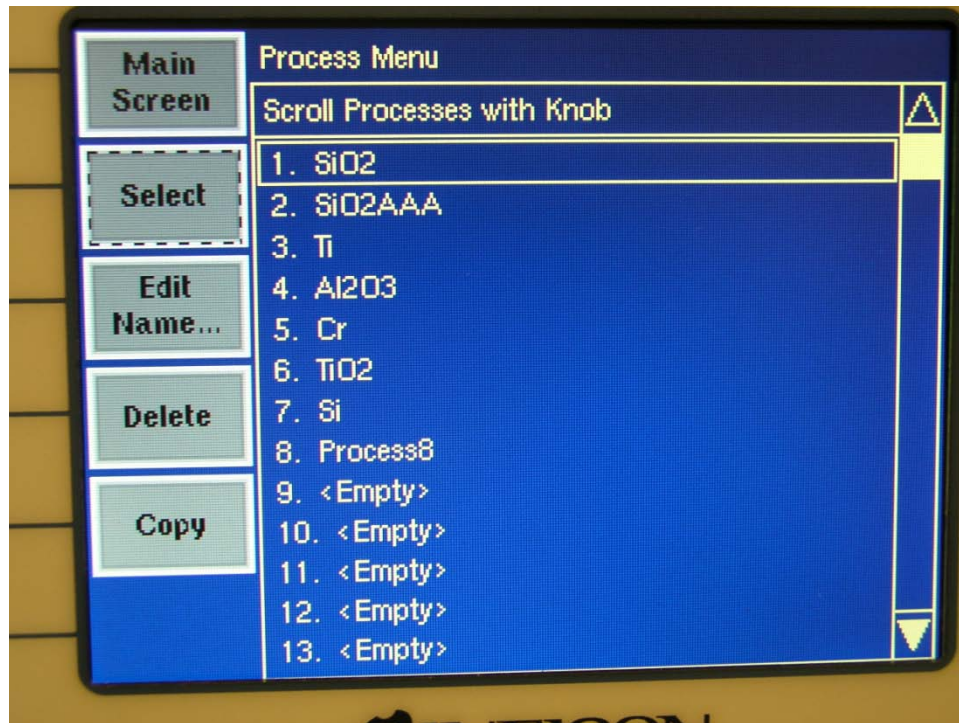


Figure 8 – List of Processes / Scroll to Process / Select process



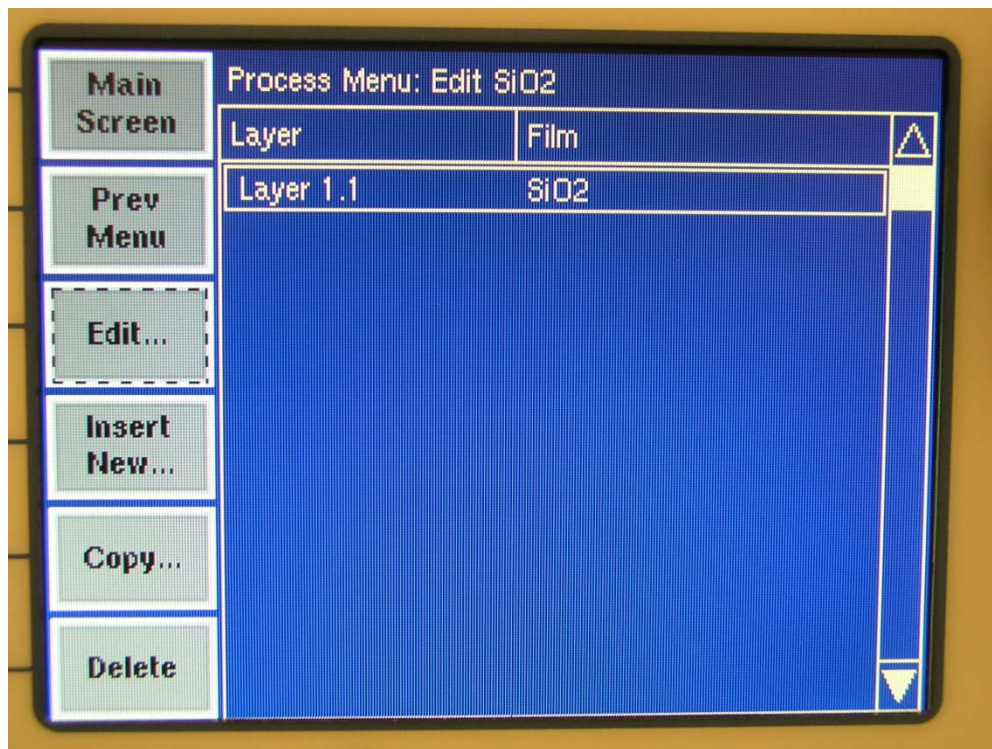


Figure 9 - Choose process / Edit

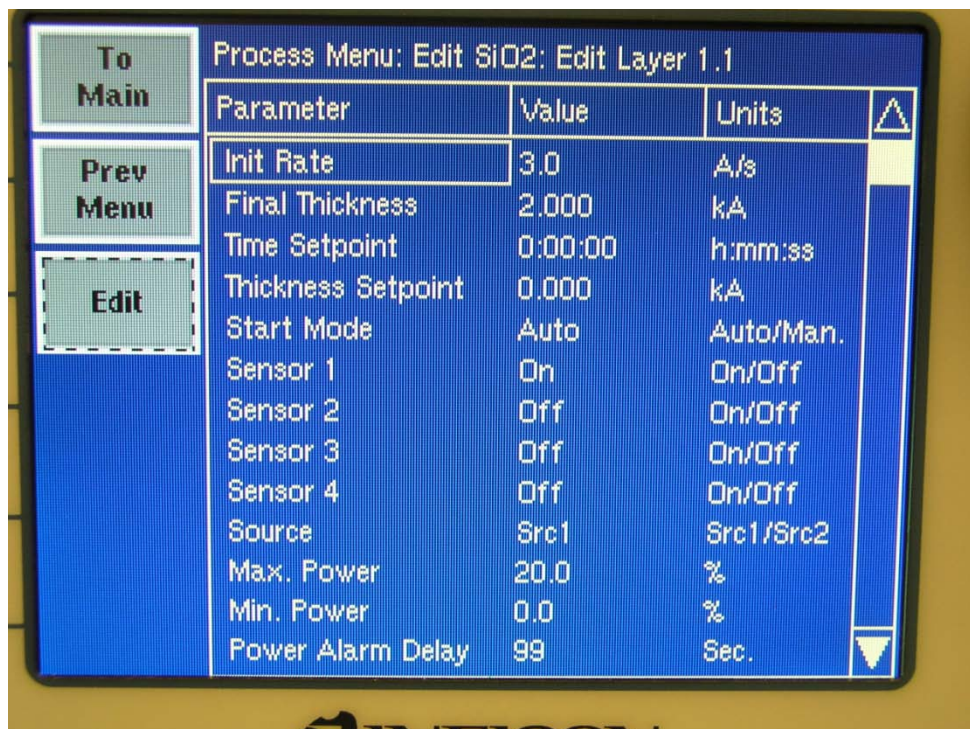


Figure 10 – Process Edit Screen

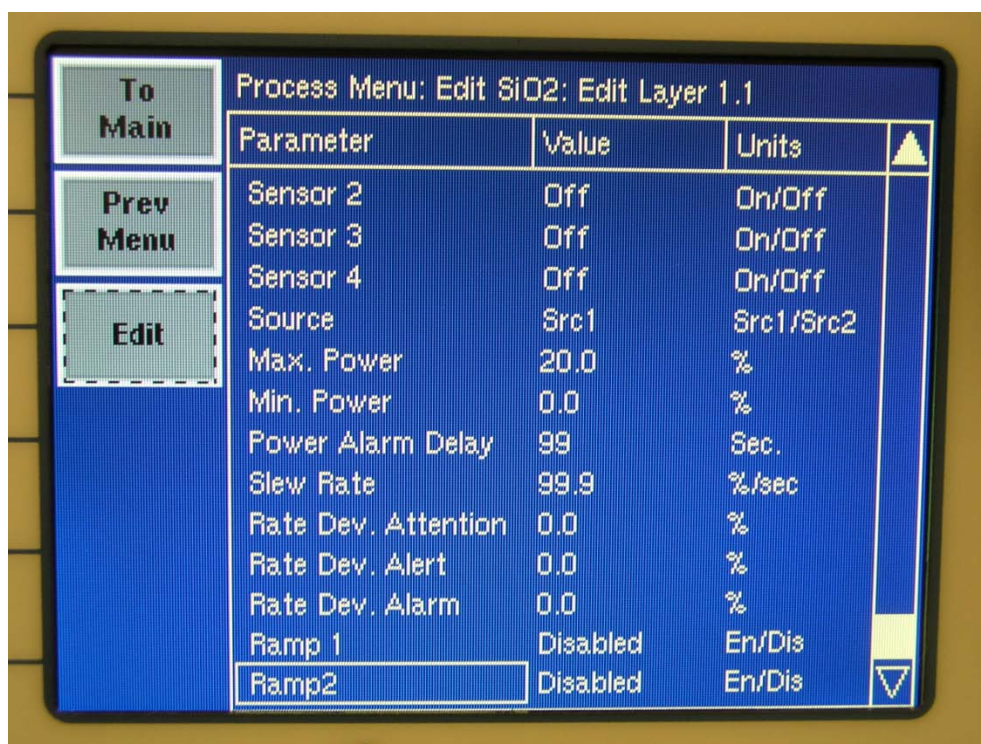


Figure 11 – Process Edit Screen, cont'd

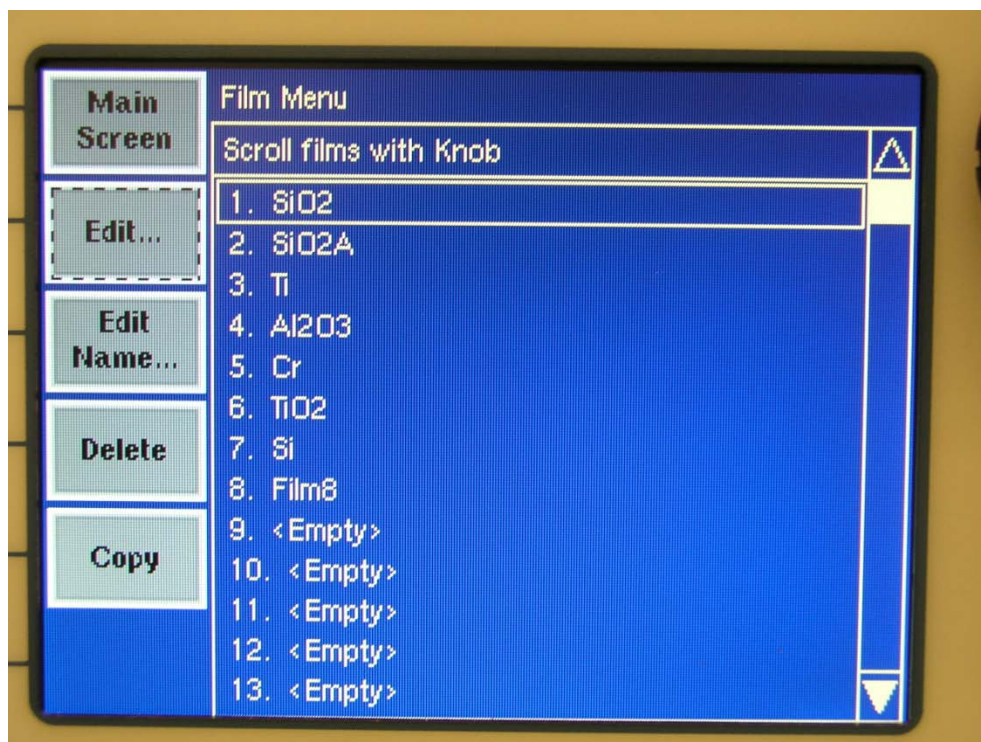


Figure 12 – Film Menu / Scroll Films with Knob



<div>To Main</div> <div>Prev Menu</div> <div>Edit</div> <div>Film Conds...</div> <div>Deposit Controls...</div> <div>Configure Sensors...</div>	Film Menu: Edit SiO2			
	Parameter	Value	Units	▲
	P Term	10	None	▼
	I Term	1.0	Sec.	
	D Term	0.0	Sec.	
	Film Tooling	100	%	
	Pocket	1		
	Xtal Quality, Rate Dev	86	%	
	Xtal Quality, Counts	Disabled		
	Xtal Stability, Single	Disabled	Hz	
	Xtal Stability, Total	Disabled	Hz	
	Material	SiliconDioxide		
	Density	2.20	gm/cc	
	Zfactor	1.070		▼

Figure 13 – Film Edit Menu

<div>To Main</div> <div>Prev Menu</div> <div>Edit</div>	Film Menu: Edit SiO2: Film Conditions			
	Parameter	Value	Units	▲
	Ramp1 Power	7.0	%	▼
	Ramp1 Time	0:01:00	h:mm:ss	
	Soak1 Time	0:00:30	h:mm:ss	
	Ramp2 Power	8.0	%	
	Ramp2 Time	0:01:00	h:mm:ss	
	Soak2 Time	0:00:30	h:mm:ss	
	Feed Power	0.0	%	
	Ramp Time	0:00:00	h:mm:ss	
	Feed Time	0:00:00	h:mm:ss	
	Idle Power	0.0	%	
	Ramp Time	0:00:00	h:mm:ss	
				▼

Figure 14 – Film Conditions

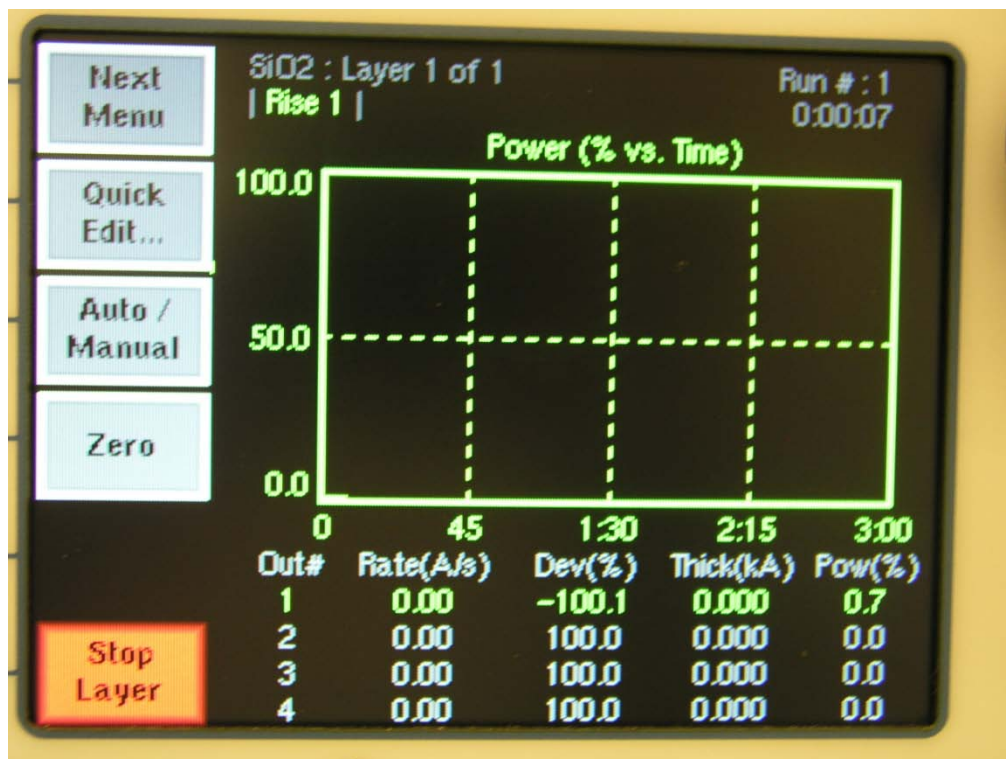


Figure 15 – Quick Edit Selection Screen

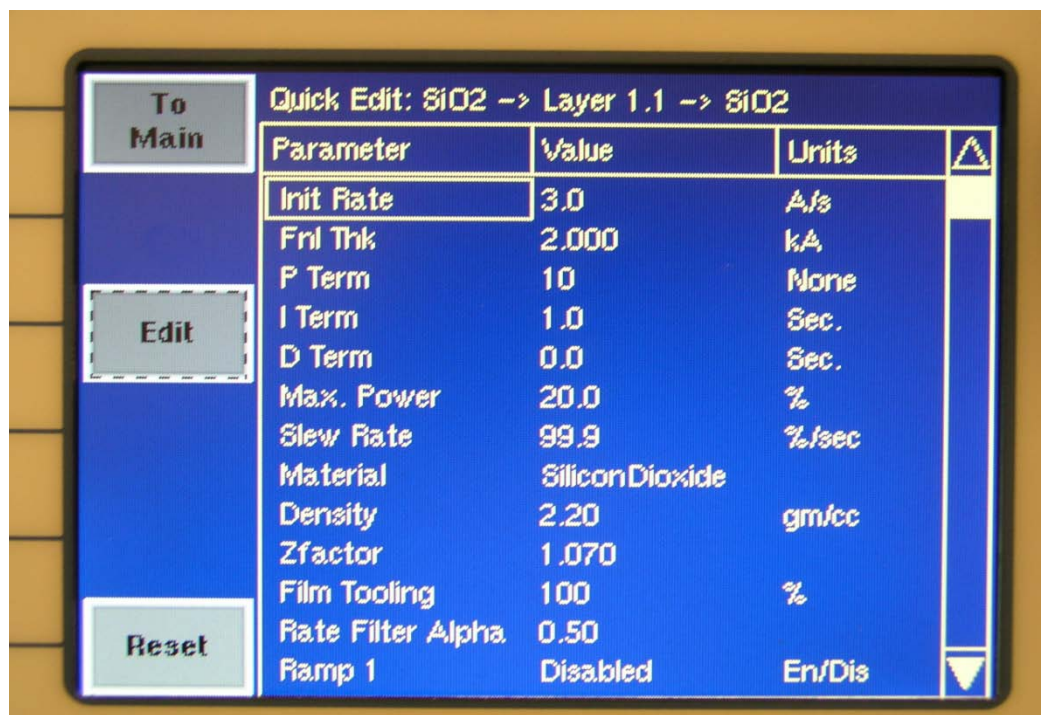


Figure 16 – Quick Edit Screen

## Appendix

### A. Material Parameters

In the table below, an \* is used to indicate that the material's Z Factor is not known. A method of determining Z Factor empirically follows the materials table.

Formula	Density	Z-Ratio	Material Name
Ag	10.500	0.529	Silver
AgBr	6.470	1.180	Silver Bromide
AgCl	5.560	1.320	Silver Chloride
Al	2.700	1.080	Aluminum
Al <sub>2</sub> O <sub>3</sub>	3.970	0.336	Aluminum Oxide
Al <sub>4</sub> C <sub>3</sub>	2.360	*1.000	Aluminum Carbide
AlF <sub>3</sub>	3.070	*1.000	Aluminum Fluoride
AlN	3.260	*1.000	Aluminum Nitride
AlSb	4.360	0.743	Aluminum Antimonide
As	5.730	0.966	Arsenic
As <sub>2</sub> Se <sub>3</sub>	4.750	*1.000	Arsenic Selenide
Au	19.300	0.381	Gold
B	2.370	0.389	Boron
B <sub>2</sub> O <sub>3</sub>	1.820	*1.000	Boron Oxide
B <sub>4</sub> C	2.370	*1.000	Boron Carbide
BN	1.860	*1.000	Boron Nitride
Ba	3.500	2.100	Barium
BaF <sub>2</sub>	4.886	0.793	Barium Fluoride
BaN <sub>2</sub> O <sub>6</sub>	3.244	1.261	Barium Nitrate
BaO	5.720	*1.000	Barium Oxide
BaTiO <sub>3</sub>	5.999	0.464	Barium Titanate (Tetr)
BaTiO <sub>3</sub>	6.035	0.412	Barium Titanate (Cubic)
Be	1.850	0.543	Beryllium
BeF <sub>2</sub>	1.990	*1.000	Beryllium Fluoride
BeO	3.010	*1.000	Beryllium Oxide
Bi	9.800	0.790	Bismuth
Bi <sub>2</sub> O <sub>3</sub>	8.900	*1.000	Bismuth Oxide
Bi <sub>2</sub> S <sub>3</sub>	7.390	*1.000	Bismuth Trisulphide
Bi <sub>2</sub> Se <sub>3</sub>	6.820	*1.000	Bismuth Selenide
Bi <sub>2</sub> Te <sub>3</sub>	7.700	*1.000	Bismuth Telluride
BiF <sub>3</sub>	5.320	*1.000	Bismuth Fluoride
C	2.250	3.260	Carbon (Graphite)
C	3.520	0.220	Carbon (Diamond)
C <sub>8</sub> H <sub>8</sub>	1.100	*1.000	Parlyene (Union Carbide)



Formula	Density	Z-Ratio	Material Name
Ca	1.550	2.620	Calcium
CaF <sub>2</sub>	3.180	0.775	Calcium Fluoride
CaO	3.350	*1.000	Calcium Oxide
CaO-SiO <sub>2</sub>	2.900	*1.000	Calcium Silicate (3)
CaSO <sub>4</sub>	2.962	0.955	Calcium Sulfate
CaTiO <sub>3</sub>	4.100	*10~	Calcium Titanate
CaWO <sub>4</sub>	6.060	*1.000	Calcium Tungstate
Cd	8.640	0.682	Cadmium
CdF <sub>2</sub>	6.640	*1.000	Cadmium Fluoride
CdO	8.150	*1.000	Cadmium Oxide
CdS	4.830	1.020	Cadmium Sulfide
CdSe	5.810	*1.000	Cadmium Selenide,
CdTe	6.200	0.980	Cadmium Telluride
Ce	6.780	*1.000	Cerium
CeF <sub>3</sub>	6.160	*1.000	Cerium (III) Fluoride
CeO <sub>2</sub>	7.130	*1.000	Cerium (IV) Dioxide
Co	8.900	0.343	Cobalt
CoO	6.440	0.412	Cobalt Oxide
Cr	7.200	0.305	Chromium
Cr <sub>2</sub> O <sub>3</sub>	5.210	*1.000	Chromium (III) Oxide
Cr <sub>3</sub> C <sub>2</sub>	6.680	*1.000	Chromium Carbide
CrB	6.170	*1.000	Chromium Boride
Cs	1.870	*1.000	Cesium
Cs <sub>2</sub> SO <sub>4</sub>	4.243	1.212	Cesium Sulfate
CsBr	4.456	1.410	Cesium Bromide
CsCl	3.988	1.399	Cesium Chloride
CsI	4.516	1.542	Cesium Iodide
Cu	8.930	0.437	Copper
Cu <sub>2</sub> O	6.000	*1.000	Copper Oxide
Cu <sub>2</sub> S	5.600	0.690	Copper (I) Sulfide (Alpha)
Cu <sub>2</sub> S	5.800	0.670	Copper (I) Sulfide (Beta)
CuS	4.600	0.820	Copper (II) Sulfide
Dy	8.550	0.600	Dysprosium
Dy <sub>2</sub> O <sub>3</sub>	7.810	*1.000	Dysprosium Oxide
Er	9.050	0.740	Erbium
Er <sub>2</sub> O <sub>3</sub>	8.640	*1.000	Erbium Oxide
Eu	5.260	*1.000	Europium
EuF <sub>2</sub>	6.500	*1.000	Europium Fluoride



Formula	Density	Z-Ratio	Material Name
Fe	7.860	0.349	Iron
Fe <sub>2</sub> O <sub>3</sub>	5.240	*1.000	Iron Oxide
FeO	5.700	*1.000	Iron Oxide
FeS	4.840	*1.000	Iron Sulphide
Ga	5.930	0.593	Gallium
Ga <sub>2</sub> O <sub>3</sub>	5.880	*1.000	Gallium Oxide (B)
GaAs	5.310	1.590	Gallium Arsenide
GaN	6.100	*1.000	Gallium Nitride
GaP	4.100	*1.000	Gallium Phosphide
GaSb	5.600	*1.000	Gallium Antimonide
Gd	7.890	0.670	Gadolinium
Gd <sub>2</sub> O <sub>3</sub>	7.410	*1.000	Gadolinium Oxide
Ge	5.350	0.516	Germanium
Ge <sub>3</sub> N <sub>2</sub>	5.200	*1.000	Germanium Nitride
GeO <sub>2</sub>	6.240	*1.000	Germanium Oxide
GeTe	6.200	*1.000	Germanium Telluride
Hf	13.090	0.360	Hafnium
HfB <sub>2</sub>	10.500	*1.000	Hafnium Boride,
HfC	12.200	*1.000	Hafnium Carbide
HfN	13.800	*1.000	Hafnium Nitride
HfO <sub>2</sub>	9.680	*1.000	Hafnium Oxide
HfSi <sub>2</sub>	7.200	*1.000	Hafnium Silicide
Hg	13.460	0.740	Mercury
Ho	8.800	0.580	Holmium
Ho <sub>2</sub> O <sub>3</sub>	8.410	*1.000	Holmium Oxide
In	7.300	0.841	Indium
In <sub>2</sub> O <sub>3</sub>	7.180	*1.000	Indium Sesquioxide
In <sub>2</sub> Se <sub>3</sub>	5.700	*1.000	Indium Selenide
In <sub>2</sub> Te <sub>3</sub>	5.800	*1.000	Indium Telluride
InAs	5.700	*1.000	Indium Arsenide
InP	4.800	*1.000	Indium Phosphide
InSb	5.760	0.769	Indium Antimonide
Ir	22.400	0.129	Iridium
K	0.860	10.189	Potassium
KBr	2.750	1.893	Potassium Bromide
KCl	1.980	2.050	Potassium Chloride
KF	2.480	*1.000	Potassium Fluoride
KI	3.128	2.077	Potassium Iodide

Formula	Density	Z-Ratio	Material Name
La	6.170	0.920	Lanthanum
La <sub>2</sub> O <sub>3</sub>	6.510	*1.000	Lanthanum Oxide
LaB <sub>6</sub>	2.610	*1.000	Lanthanum Boride
LaF <sub>3</sub>	5.940	*1.000	Lanthanum Fluoride
Li	0.530	5.900	Lithium
LiBr	3.470	1.230	Lithium Bromide
LiF	2.638	0.778	Lithium Fluoride
LiNbO <sub>3</sub>	4.700	0.463	Lithium Niobate
Lu	9.840	*1.000	Lutetium
Mg	1.740	1.610	Magnesium
MgAl <sub>2</sub> O <sub>4</sub>	3.600	*1.000	Magnesium Aluminate
MgAl <sub>2</sub> O <sub>6</sub>	8.000	*1.000	Spinel
MgF <sub>2</sub>	3.180	0.637	Magnesium Fluoride
MgO	3.580	0.411	Magnesium Oxide
Mn	7.200	0.377	Manganese
MnO	5.390	0.467	Manganese Oxide
MnS	3.990	0.940	Manganese (II) Sulfide
Mo	10.200	0.257	Molybdenum
Mo <sub>2</sub> C	9.180	*1.000	Molybdenum Carbide
MoB <sub>2</sub>	7.120	*1.000	Molybdenum Boride
MoO <sub>3</sub>	4.700	*1.000	Molybdenum Trioxide
MoS <sub>2</sub>	4.800	*1.000	Molybdenum Disulfide
Na	0.970	4.800	Sodium
Na <sub>3</sub> AlF <sub>6</sub>	2.900	*1.000	Cryolite
Na <sub>5</sub> Al <sub>3</sub> F <sub>14</sub>	2.900	*1.000	Chiolite
NaBr	3.200	*1.000	Sodium Bromide
NaCl	2.170	1.570	Sodium Chloride
NaClO <sub>3</sub>	2.164	1.565	Sodium Chlorate
NaF	2.558	0.949	Sodium Fluoride
NaNO <sub>3</sub>	2.270	1.194	Sodium Nitrate
Nb	8.578	0.492	Niobium (Columbium)
Nb <sub>2</sub> O <sub>3</sub>	7.500	*1.000	Niobium Trioxide
Nb <sub>2</sub> O <sub>5</sub>	4.470	*1.000	Niobium (V) Oxide
NbB <sub>2</sub>	6.970	*1.000	Niobium Boride
NbC	7.820	*1.000	Niobium Carbide
NbN	8.400	*1.000	Niobium Nitride
Nd	7.000	*1.000	Neodymium
Nd <sub>2</sub> O <sub>3</sub>	7.240	*1.000	Neodymium Oxide
NdF <sub>3</sub>	6.506	*1.000	Neodymium Fluoride

Formula	Density	Z-Ratio	Material Name
Ni	8910	0.331	Nickel
NiCr	8.500	*1.000	Nichrome
NiCrFe	8.500	*10~	Inconel
NiFe	8.700	*1.000	Permalloy
NiFeMo	8.900	*10~	Supermalloy
NiO	7.450	*1.000	Nickel Oxide
P <sub>3</sub> N <sub>5</sub>	2.510	*1.000	Phosphorus Nitride
Pb	11.300	1.130	Lead
PbCl <sub>2</sub>	5.850	*1.000	Lead Chloride
PbF <sub>2</sub>	8.240	0.661	Lead Fluoride
PbO	9.530	*1.000	Lead Oxide
PbS	7.500	0.566	Lead Sulfide
PbSe	8.100	*1.000	Lead Selenide
PbSnO <sub>3</sub>	8.100	*1.000	Lead Stannate
PbTe	8.160	0.651	Lead Telluride
Pd	12.038	0.357	Palladium
PdO	8.310	*1.000	Palladium Oxide
Po	9.400	*1.000	Polonium
Pr	6.780	*1.000	Praseodymium
Pr <sub>2</sub> O <sub>3</sub>	6.880	*1.000	Praseodymium Oxide
Pt	21.400	0.245	Platinum
PtO <sub>2</sub>	10.200	*1.000	Platinum Oxide
Ra	5.000	*1.000	Radium
Rb	1.530	2.540	Rubidium
RbI	3.550	*1.000	Rubidium Iodide
Re	21.040	0.150	Rhenium
Rh	12.410	0.210	Rhodium
Ru	12.362	0.182	Ruthenium
S <sub>8</sub>	2.070	2.290	Sulphur
Sb	6.620	0.768	Antimony
Sb <sub>2</sub> O <sub>3</sub>	5.200	*1.000	Antimony Trioxide
Sb <sub>2</sub> S <sub>3</sub>	4.640	*1.000	Antimony Trisulfide
Sc	3.000	0.910	Scandium
Sc <sub>2</sub> O <sub>3</sub>	3.860	*1.000	Scandium Oxide
Se	4.810	0.864	Selenium
Si	2.320	0.712	Silicon
Si <sub>3</sub> N <sub>4</sub>	3.440	*1000	Silicon Nitride
SiC	3.220	*1.000	Silicon Carbide
SiO	2.130	0.870	Silicon (II) Oxide
SiO <sub>2</sub>	2.648	1.000	Silicon Dioxide

Formula	Density	Z-Ratio	Material Name
Sm	7.540	0.890	Samarium
Sm <sub>2</sub> O <sub>3</sub>	7.430	*1.000	Samarium Oxide
Sn	7.300	0.724	Tin
SnO <sub>2</sub>	6.950	*1.000	Tin Oxide
SnS	5.080	*1.000	Tin Sulfide
SnSe	6.180	*1.000	Tin Selenide
SnTe	6.440	*1.000	Tin Telluride
Sr	2.600	*1.000	Strontium
SrF <sub>2</sub>	4.277	0.727	Strontium Fluoride
SrO	4.990	0.517	Strontium Oxide
Ta	16.600	0.262	Tantalum
Ta <sub>2</sub> O <sub>5</sub>	8.200	0.300	Tantalum (V) Oxide
TaB <sub>2</sub>	11.150	*1.000	Tantalum Boride
TaC	13.900	*1.000	Tantalum Carbide
TaN	16.300	*1.000	Tantalum Nitride
Tb	8.270	0.660	Terbium
Tc	11.500	*1.000	Technetium
Te	6.250	0.900	Tellurium
TeO <sub>2</sub>	5.990	0.862	Tellurium Oxide
Th	11.694	0.484	Thorium
ThF <sub>4</sub>	6.320	*1.000	Thorium.(IV) Fluoride
ThO <sub>2</sub>	9.860	0.284	Thorium Dioxide
ThOF <sub>2</sub>	9.100	*1.000	Thorium Oxyfluoride
Ti	4.500	0.628	Titanium
Ti <sub>2</sub> O <sub>3</sub>	4.600	*1.000	Titanium Sesquioxide
TiB <sub>2</sub>	4.500	*1.000	Titanium Boride
TiC	4.930	*1.000	Titanium Carbide
TiN	5.430	*1.000	Titanium Nitride
TiO	4.900	*1.000	Titanium Oxide
TiO <sub>2</sub>	4.260	0.400	Titanium (IV) Oxide
Tl	11.850	1.550	Thallium
TlBr	7.560	*1.000	Thallium Bromide
TlCl	7.000	*1.000	Thallium Chloride
TlI	7.090	*1.000	Thallium Iodide (B)
U	19.050	0.238	Uranium
U <sub>3</sub> O <sub>8</sub>	8.300	*1.000	Tri Uranium Octoxide
U <sub>4</sub> O <sub>9</sub>	10.969	0.348	Uranium Oxide
UO <sub>2</sub>	10.970	0.286	Uranium Dioxide

Formula	Density	Z-Ratio	Material Name
V	5.960	0.530	Vanadium
V <sub>2</sub> O <sub>5</sub>	3.360	*1.000	Vanadium Pentoxide
VB <sub>2</sub>	5.100	*1.000	Vanadium Boride
VC	5.770	*1.000	Vanadium Carbide
VN	6.130	*1.000	Vanadium Nitride
VO <sub>2</sub>	4.340	*1.000	Vanadium Dioxide
W	19.300	0.163	Tungsten
WB <sub>2</sub>	10.770	*1.000	Tungsten Boride
WC	15.600	0.151	Tungsten Carbide
WO <sub>3</sub>	7.160	*1.000	Tungsten Trioxide
WS <sub>2</sub>	7.500	*1.000	Tungsten Disulphide
WSi <sub>2</sub>	9.400	*1.000	Tungsten Suicide
Y	4.340	0.835	Yttrium
Y <sub>2</sub> O <sub>3</sub>	5.010	*1.000	Yttrium Oxide
Yb	6.980	1.130	Ytterbium
Yb <sub>2</sub> O <sub>3</sub>	9.170	*1.000	Ytterbium Oxide
Zn	7.040	0.514	Zinc
Zn <sub>3</sub> Sb <sub>2</sub>	6.300	*1.000	Zinc Antimonide
ZnF <sub>2</sub>	4.950	*1.000	Zinc Fluoride
ZnO	5.610	0.556	Zinc Oxide
ZnS	4.090	0.775	Zinc Sulfide
ZnSe	5.260	0.722	Zinc Selenide
ZnTe	6.340	0.770	Zinc Telluride
Zr	6.490	0.600	Zirconium
ZrB <sub>2</sub>	6.080	*1.000	Zirconium Boride
ZrC	6.730	0.264	Zirconium Carbide
ZrN	7.090	*1.000	Zirconium Nitride
ZrO <sub>2</sub>	5.600	*1.000	Zirconium Oxide

Z-Factor is used to match the acoustic properties of the material being deposited to the acoustic properties of the base quartz material of the sensor crystal.

$$Z\text{-Factor} = Z_q / Z_m$$

For example, the acoustic impedance of gold is Z=23.18, so:

$$\text{Gold Z-Factor} = 8.83 / 23.18 = .381$$

Unfortunately, Z Factor is not readily available for many materials. Z Factor can be calculated empirically using this method:

1. Deposit the material until Crystal Life is near 50%, or near the end of life, whichever is sooner.
2. Place a new substrate adjacent to the used quartz sensor.

3. Set QCM Density to the calibrated value; Tooling to 100%. Zero thickness.
  4. Deposit approximately 1000 to 5000 Å of material on the substrate.
  5. Use a profilometer or interferometer to measure the actual substrate film thickness.
  6. Adjust the Z Factor of the instrument until the correct thickness reading is shown.
- Another alternative is to change crystals frequently. For a crystal with 90% life, the error is negligible for even large errors in the programmed versus actual Z Factor.